

# Amorphous Transparent Conducting Oxides (TCOs) Deposited at $T \leq 100^\circ\text{C}$

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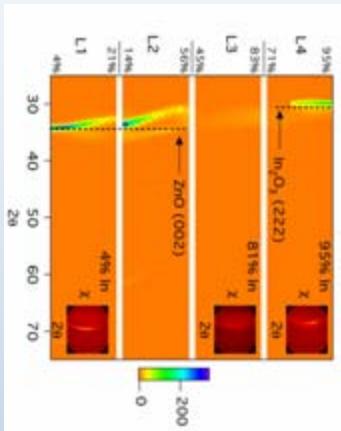
# **In-Zn-O (IZO), an Amorphous Mixed Metal Oxide Transparent Conductor**

- Low Temperature Deposition ( $T_s \leq 100\text{ }^{\circ}\text{C}$ )
- Smooth ( $R_{\text{RMS}} < 0.5\text{ nm}$ )
- Thermally Resilient
- Good Conductivity ( $\sigma \approx 3000\text{ }\Omega^{-1}\text{-cm}^{-1}$ )
- High Mobility for Amorphous material ( $\mu \approx 30\text{ cm}^2/\text{V-s}$ )

# Combinatorial Approach

## IZO: 5 - 95 %In with 4 depositions

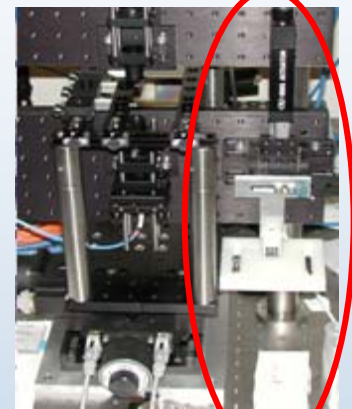
### Compositionally Graded Films



### Chemical



### Electrical



### Optical



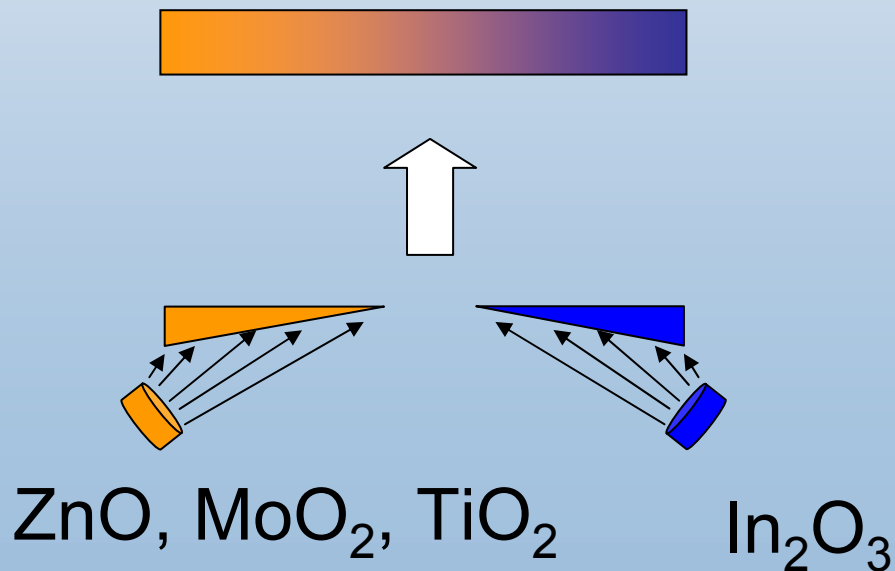
### Structural



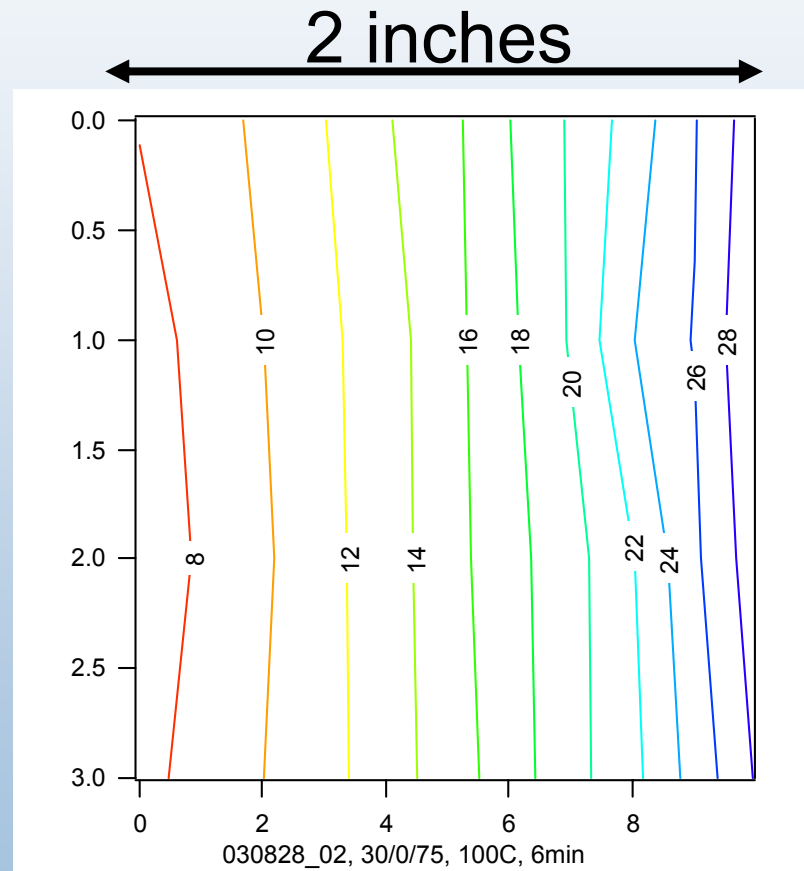
# Film Deposition

Metal Oxide  
Co-sputtering

- 5cm x 5cm  
glass substrates
- 25°C - 550°C

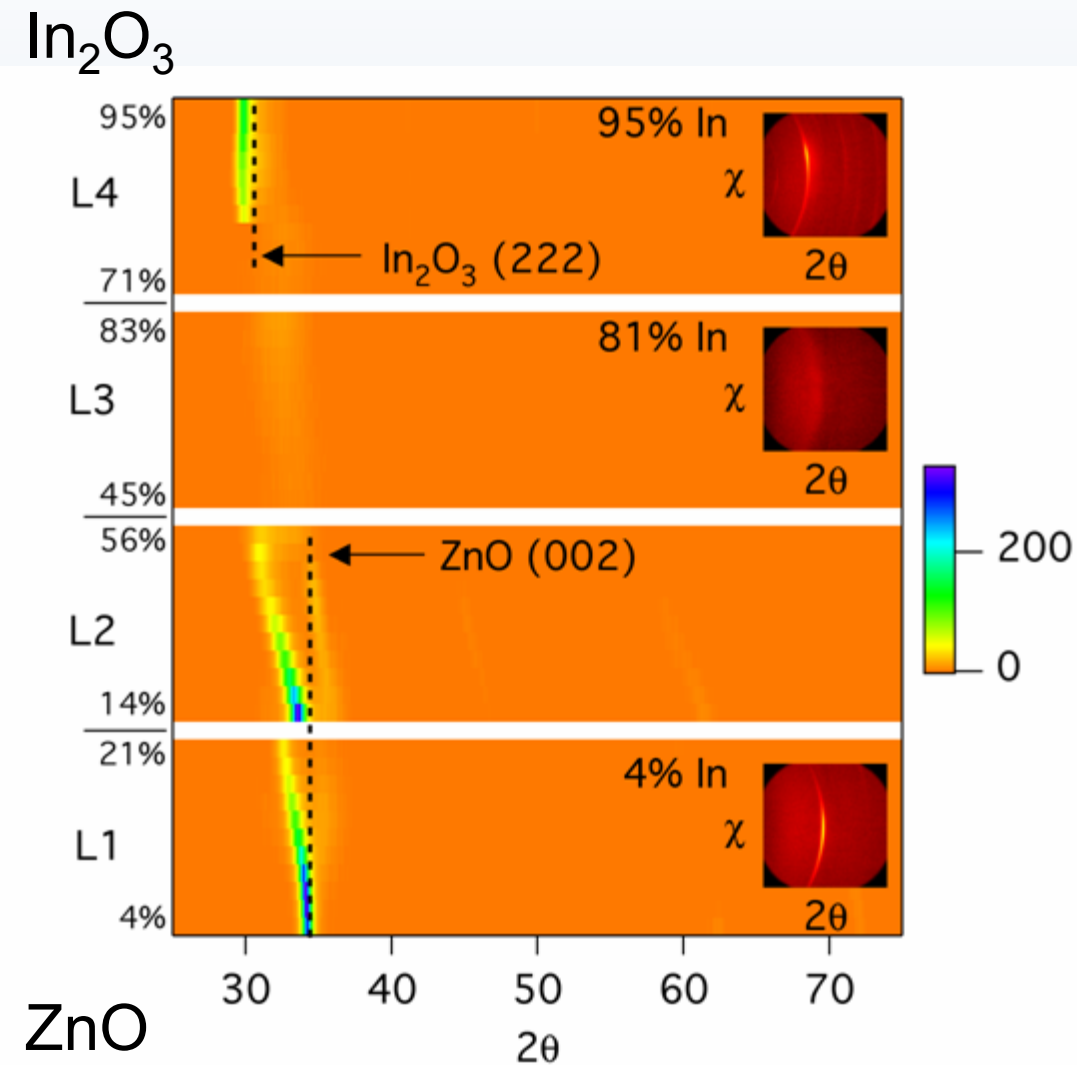


Binary In-Zn-O Library  
EPMA Analysis



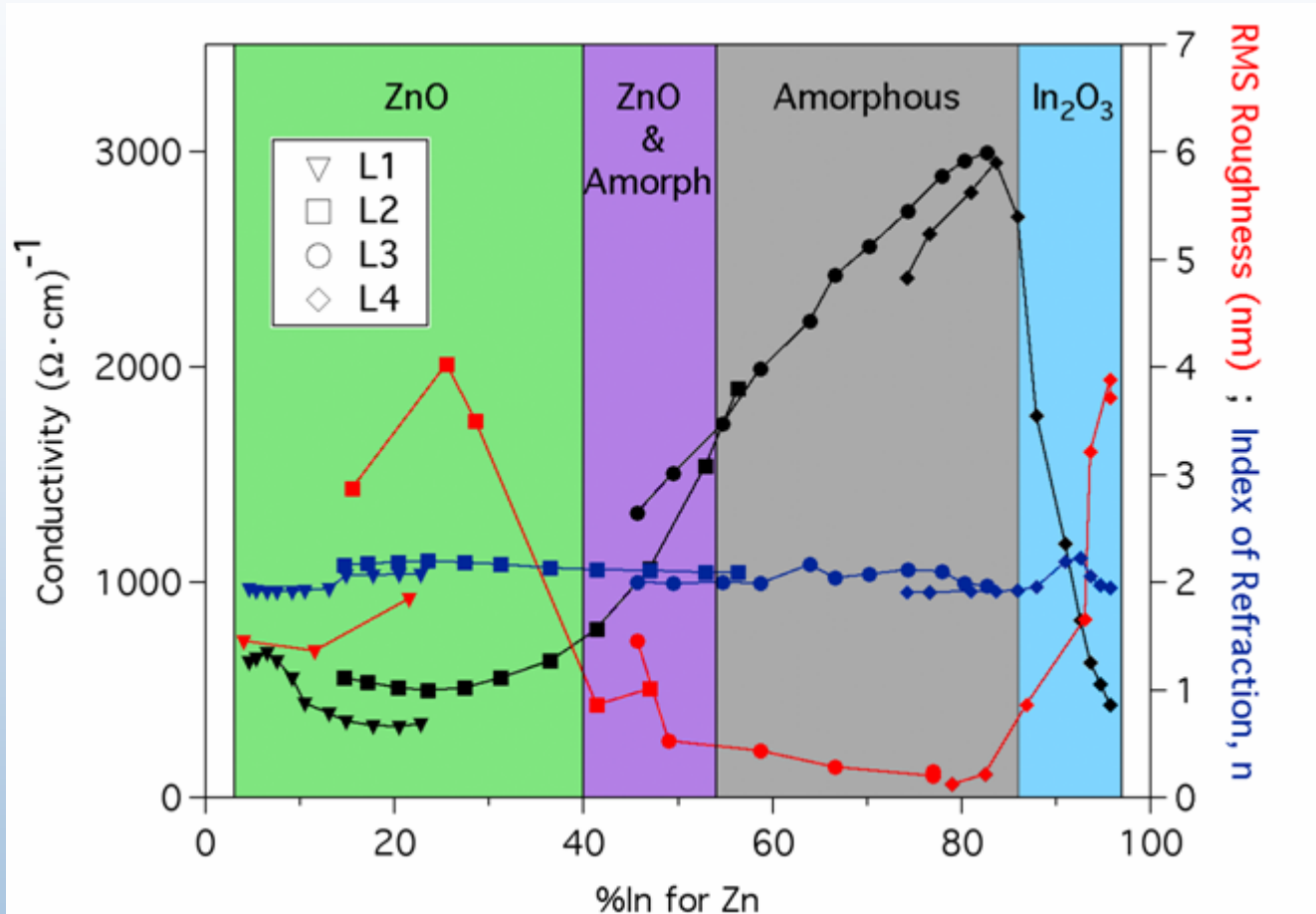
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# XRD for IZO Deposited at $T_s = 100\text{ }^\circ\text{C}$



- Amorphous  
55 - 85 % In
- Crystalline Material  
Textured

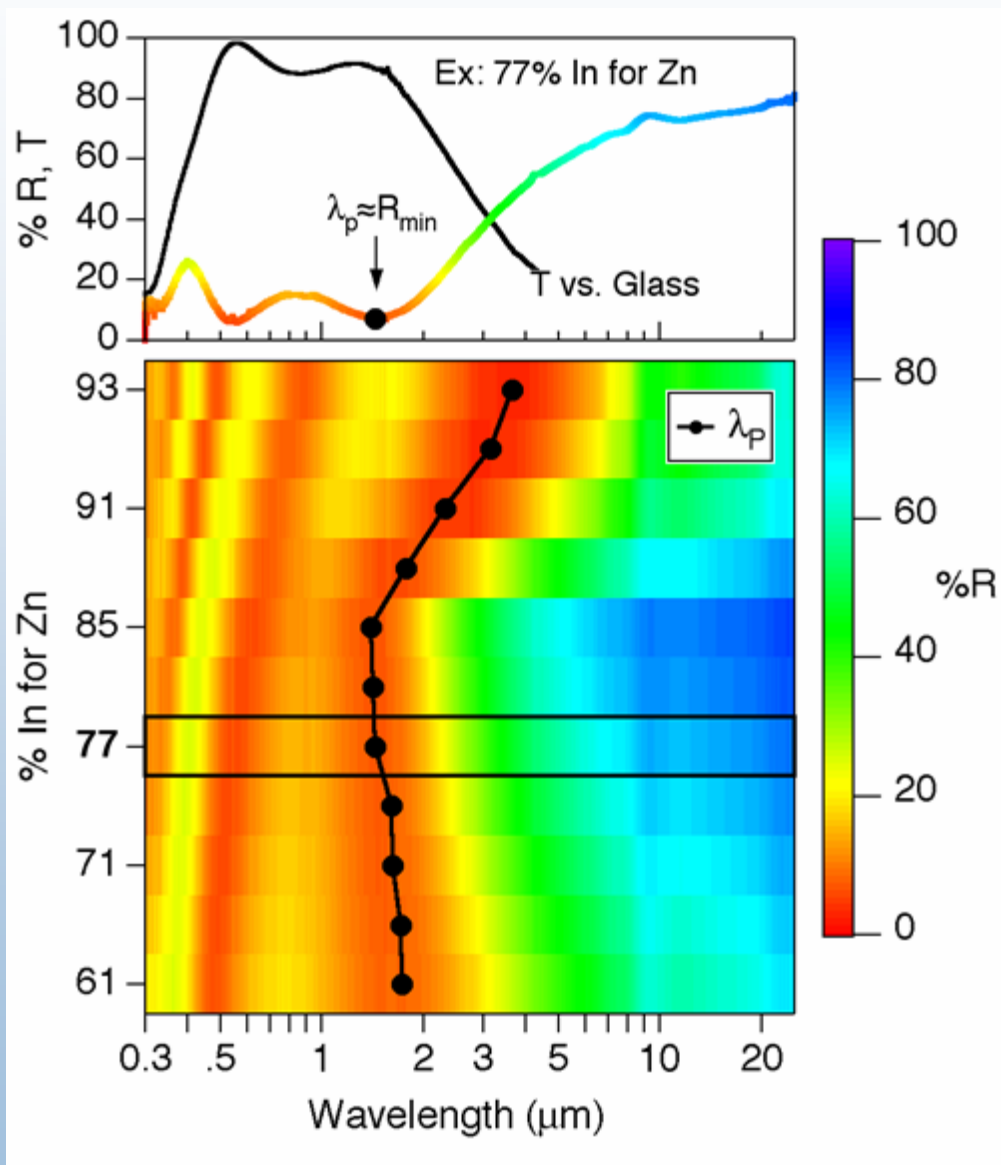
# As-dep IZO: Conductivity, Structure, Roughness & Refractive Index



**a-IZO (80/20)**  
 $\sigma = 3000 \Omega^{-1} \cdot \text{cm}^{-1}$   
 $R_{\text{RMS}} < 0.5 \text{ nm}$

Conductivity maximum occurs in smooth amorphous region.

# As-deposited IZO Optical Properties



- Typical TCO (R, T)
- Fringes give thickness
- $\lambda_p$  changes with %In
- Conductivity tracks  $\lambda_p$ .

$$\sigma = Ne\mu$$

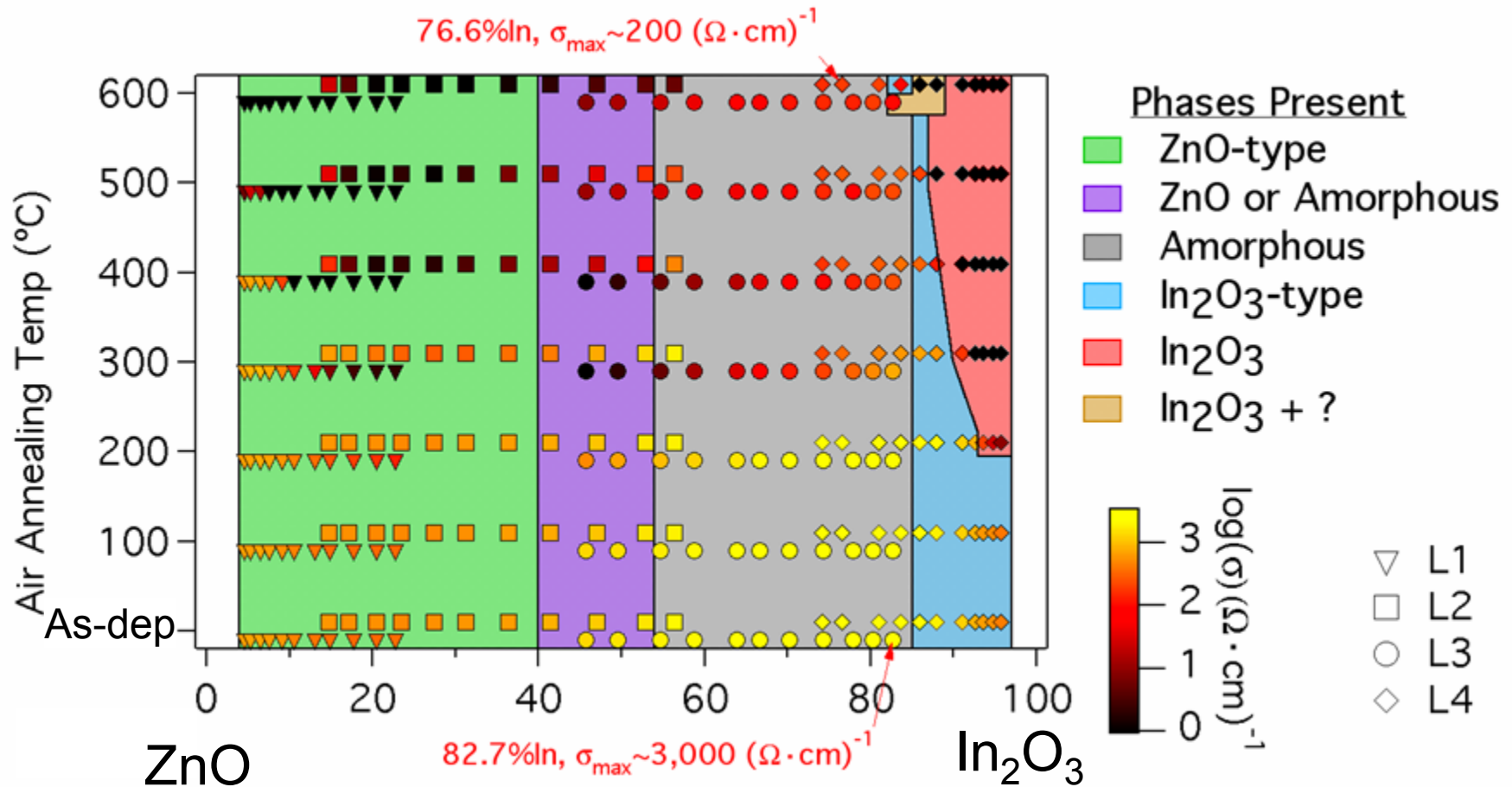
$$\lambda_p \propto \frac{1}{\sqrt{N}}$$



# Annealing of IZO Libraries

- Libraries annealed for 1 hour at target temperature
- Electrical, optical and structural properties evaluated
- Process repeated
  - 1 set of libraries annealed in air
  - 1 set of libraries annealed in argon

# IZO Annealed in Air



- Amorphous IZO generally does not recrystallize for up to 1 hr @ 600 °C
- Conductivity drop for air-annealed a- IZO 80/20 much less than crystalline material.

# Conductivity Drops Less for Argon Anneals

## Air Anneal

Final Anneal:

$$\sigma_{\max} \sim 200 (\Omega \cdot \text{cm})^{-1}$$

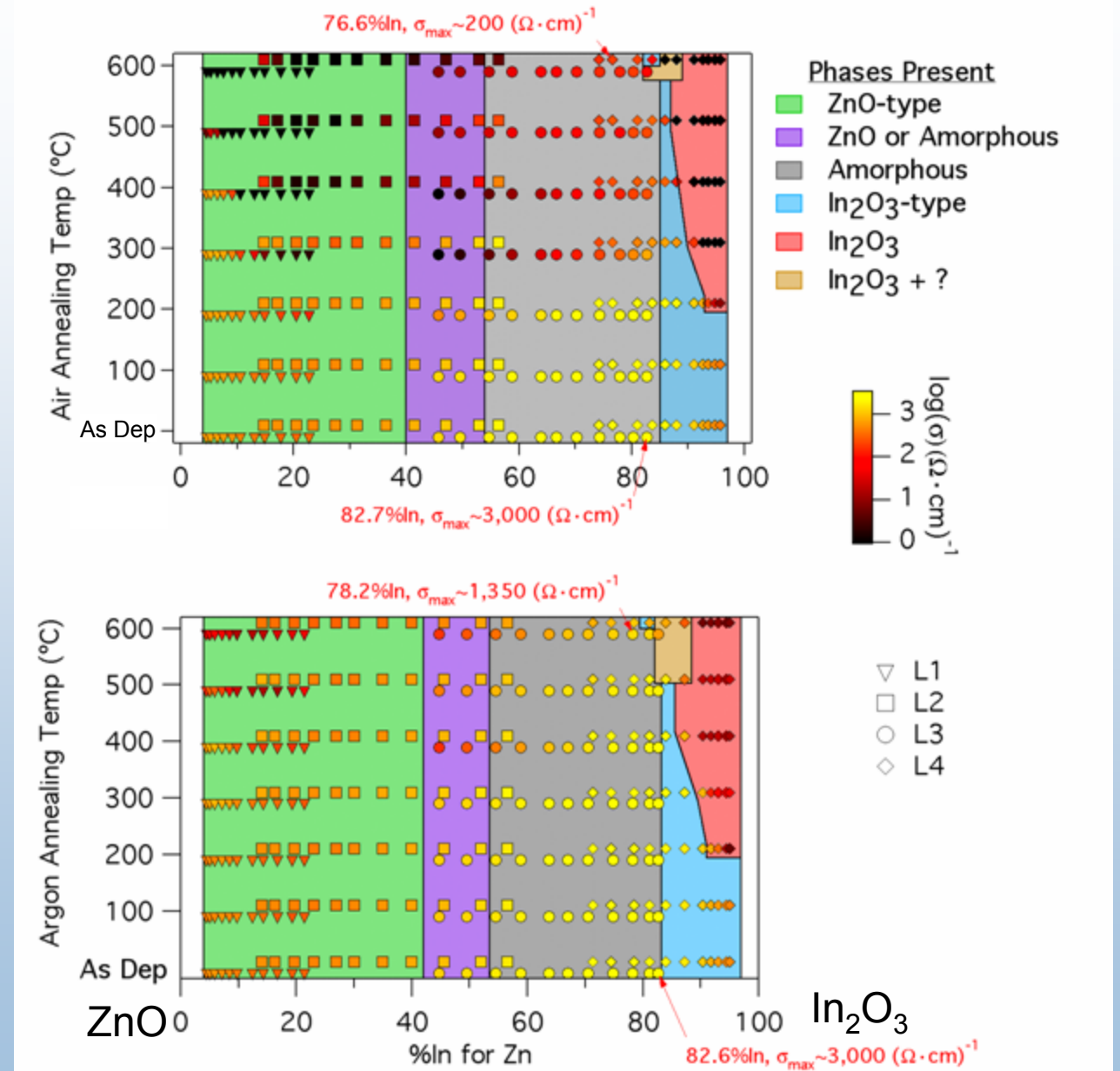
$$\sigma_{\min} \sim 0.04 (\Omega \cdot \text{cm})^{-1}$$

## Argon Anneal

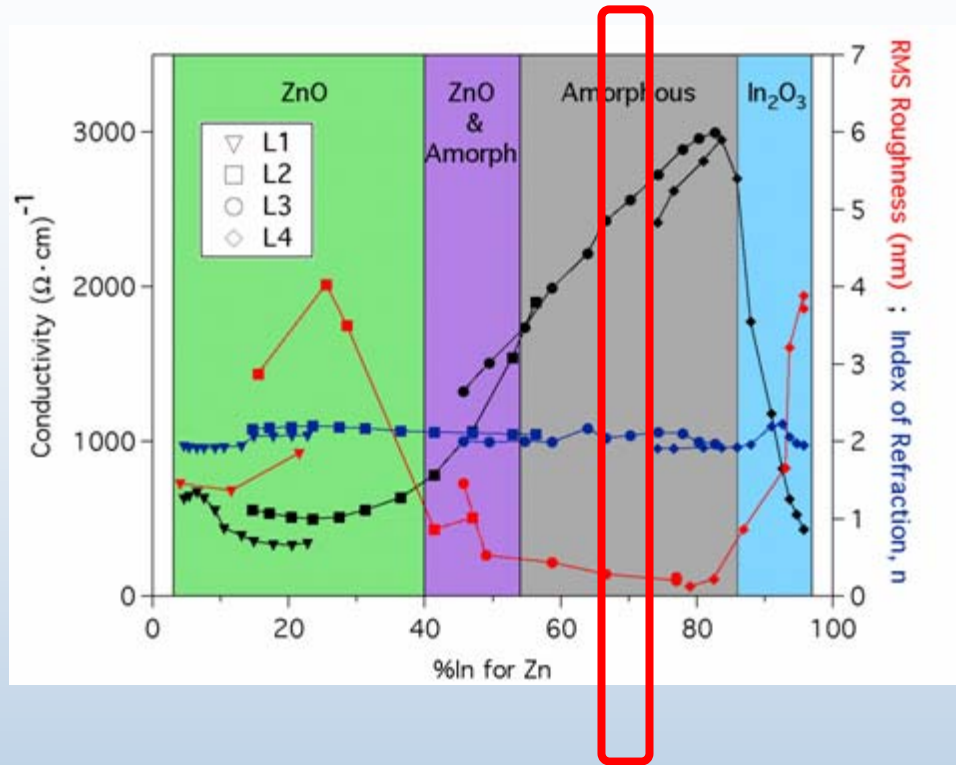
Final Anneal:

$$\sigma_{\max} \sim 1,350 (\Omega \cdot \text{cm})^{-1}$$

$$\sigma_{\min} \sim 6 (\Omega \cdot \text{cm})^{-1}$$

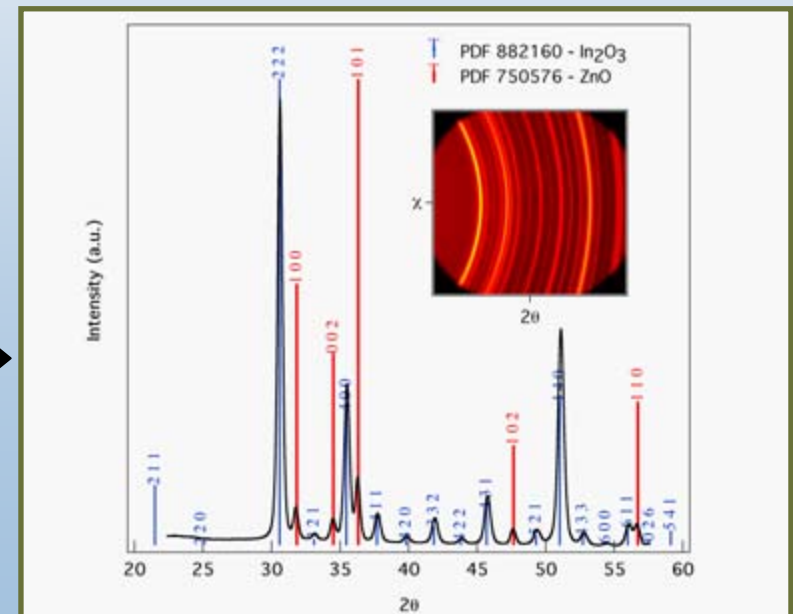


# IZO 70/30: Center of Amorphous Region



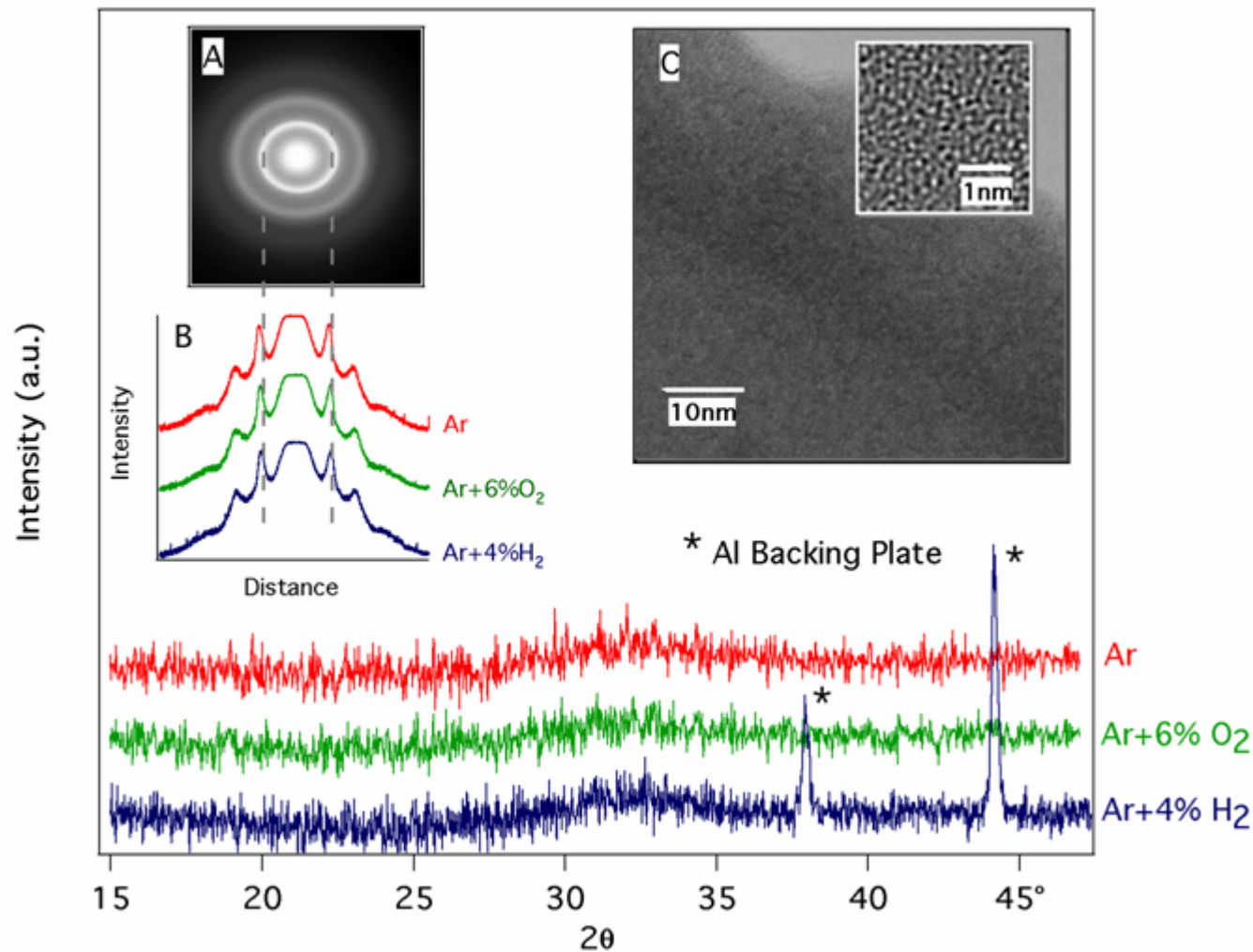
## 2" Single Composition Target

- Pressed at 25,000psi
- Sintered in air 800°C, 24hrs
- Two Phases:  $\text{ZnO}$ ,  $\text{In}_2\text{O}_3$

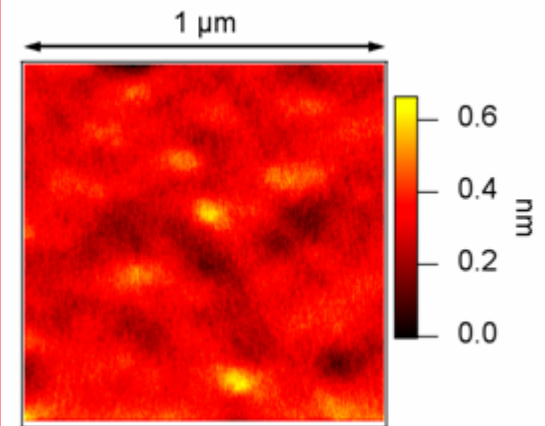


# RT Sputtered IZO 70/30 is Amorphous and Smooth

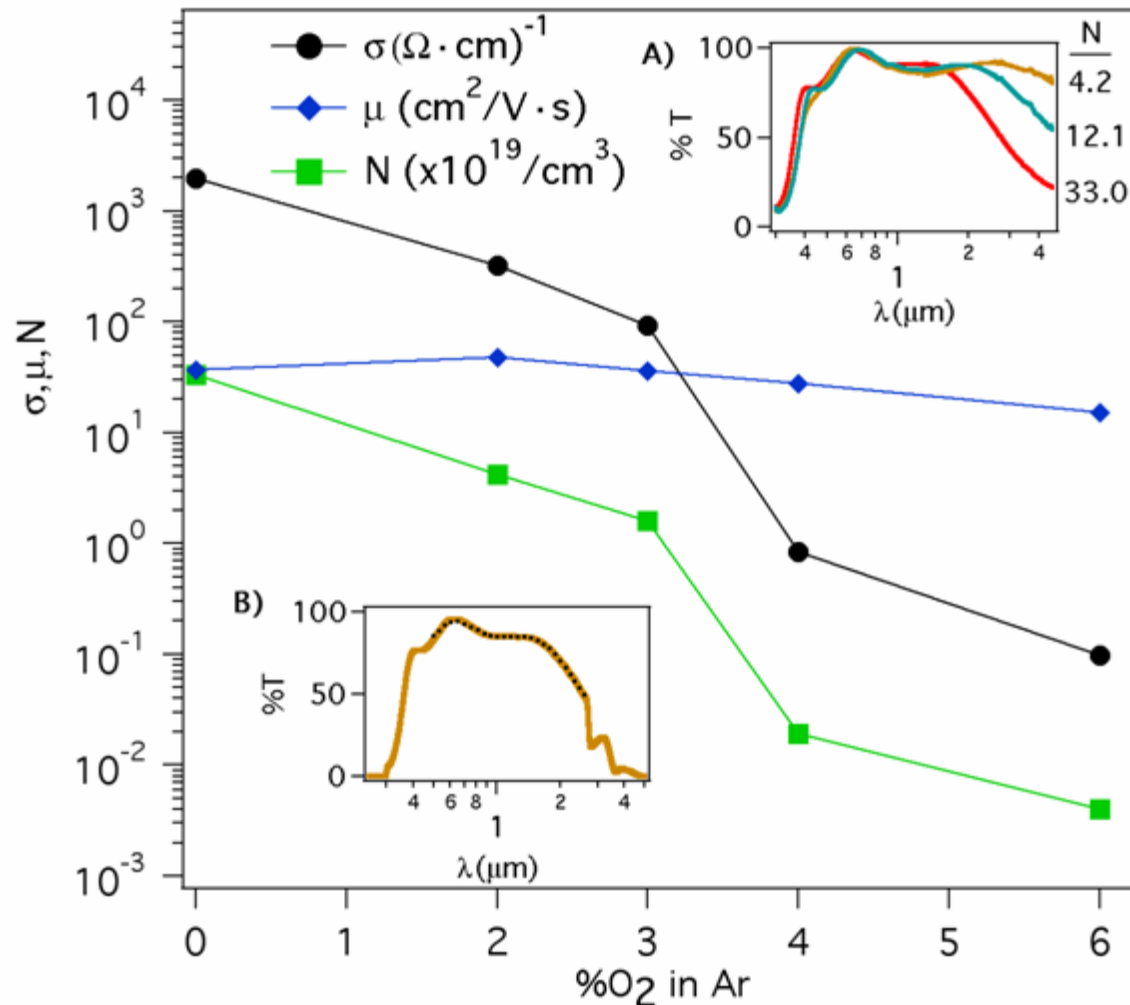
XRD, TEM



AFM

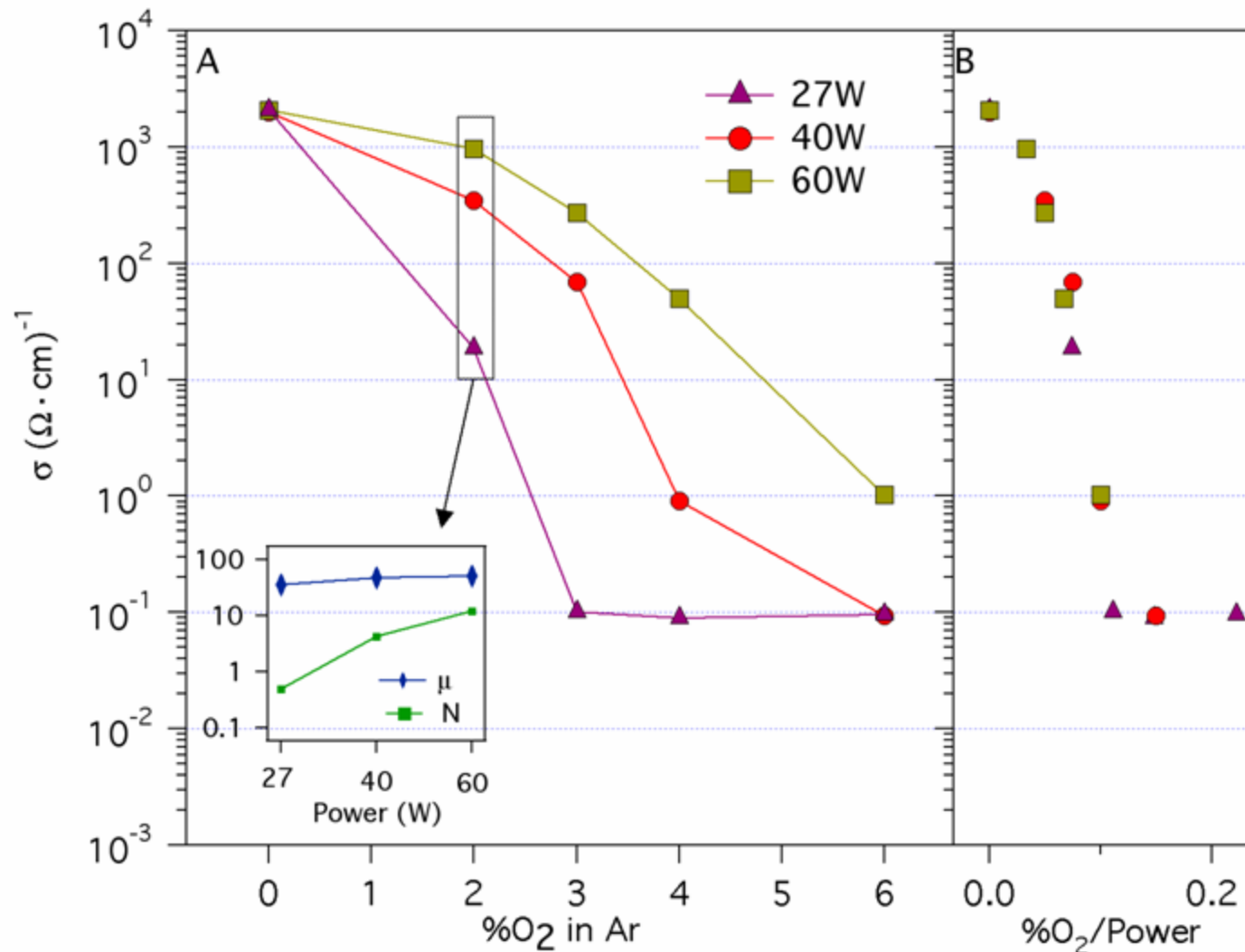


# O<sub>2</sub> in Sputter Gas Reduces Conductivity



- $N$  strongly effected by O<sub>2</sub>
- $\mu$  nearly constant
- $\mu \approx 30 \text{ cm}^2/\text{V-s}$

# Effect of O<sub>2</sub> Scales with Sputter Rate

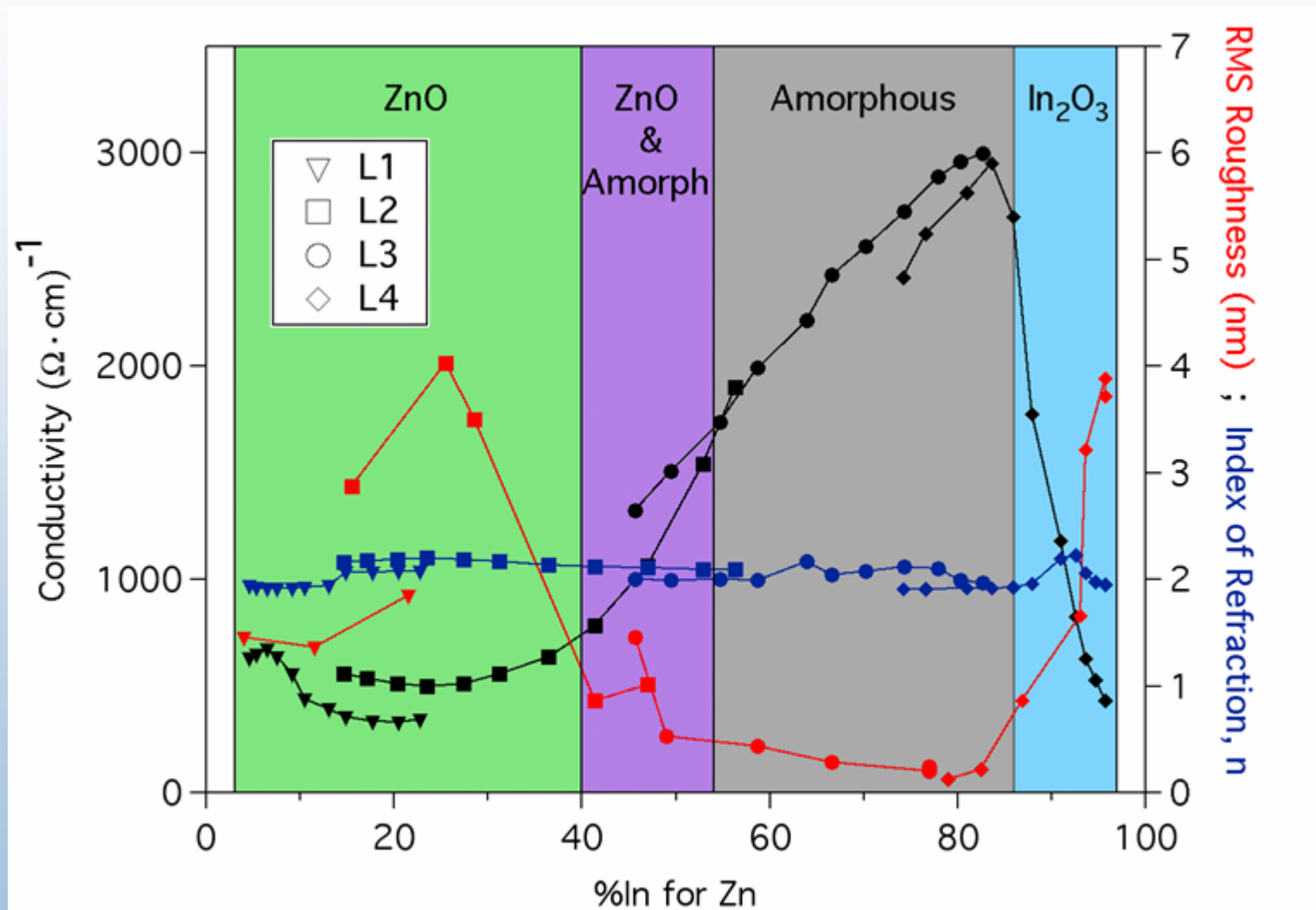


# Summary

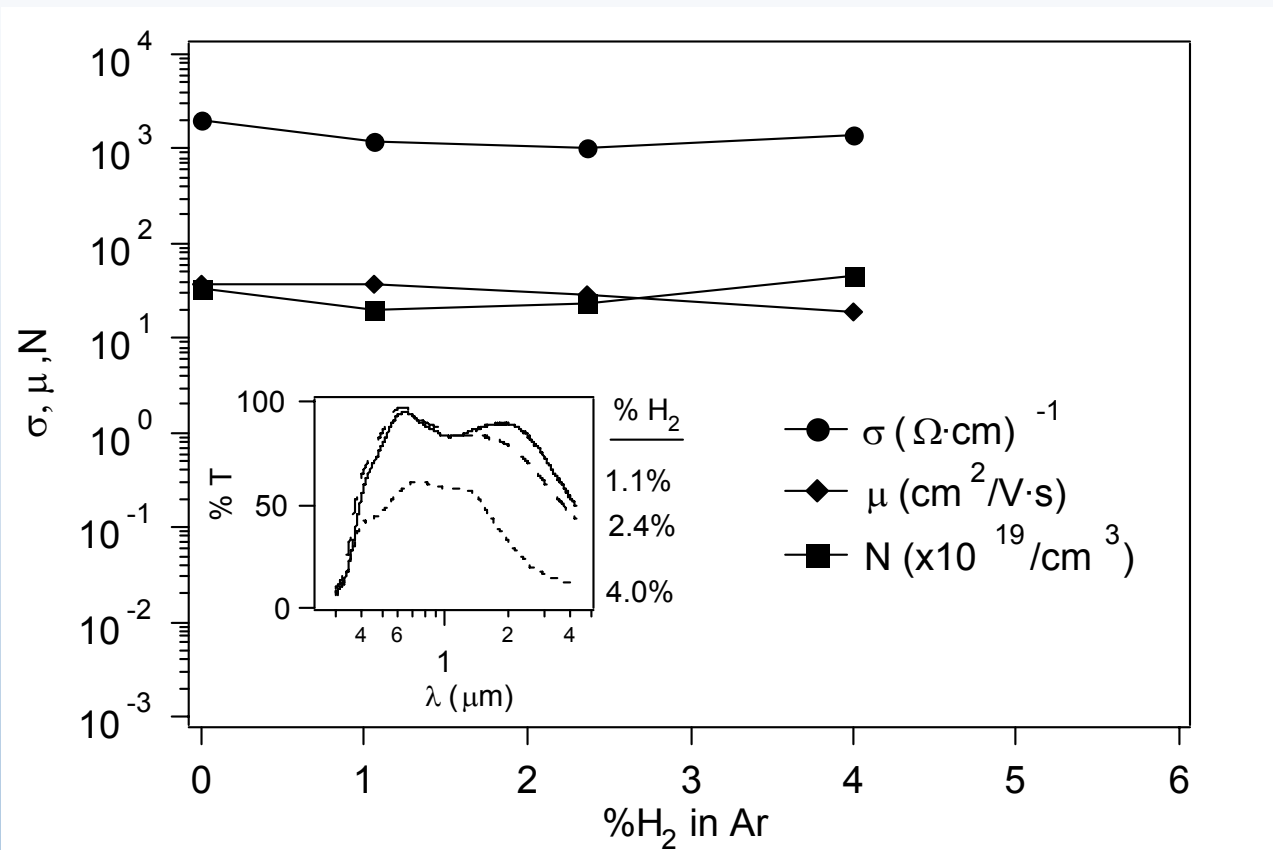
- Amorphous InZnO (a-IZO) is a very versatile TCO with:
  - Low process temperatures ( $\sim 100\text{ }^{\circ}\text{C}$ )
  - Easy to make by sputtering
  - Excellent optical and electronic properties
  - Very smooth etchable films
  - Remarkable thermal processing stability



# In-Zn-O (IZO): as-dep @ $T_s = 100\text{ }^\circ\text{C}$



# IZO: H<sub>2</sub> in Sputter Gas



- Overall, not much effect
- No increase in carrier concentration (N)
- Sample gray for 4% H<sub>2</sub>